Interrelationships of Nitrogen, Phosphorus, and Seasonal Precipitation in the Production of Bromegrass-Crested Wheatgrass Hay

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Interrelationships of Nitrogen, Phosphorus, and Seasonal Precipitation in the Production of Bromegrass-Crested Wheatgrass Hay[1]

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Nitrogen and phosphorus fertilizer on old tame grass stands under the semiarid conditions of the northern Great Plains has generally increased both seed and forage production (*5, 8, 16, 17, 19*).[2] The magnitude of the response to nitrogen fertilization was affected by seasonal precipitation and temperature (*17*).

The purpose of this study was to evaluate the effects of nitrogen and phosphorus fertilizers on the yield and composition of bromegrass (*Bromus inermis* Leyss.)–crested wheatgrass (*Agropyron desertorum* Fisch.) hay as a function of seasonal precipitation. The effect of soil fertility on the utilization of soil moisture by grass was also investigated.

PROCEDURE

This experiment was initiated in 1952 on a 12-year-old stand of bromegrass and crested wheatgrass. The soil was a calcareous Pierre clay with a cation exchange capacity of 37 meq. per 100 grams, organic matter content of 1.92 percent, pH of 7.7, and $NaHCO_3$ soluble phosphorus of 7.0 p.p.m. to a depth of 0 to 6 inches.

The fertilizer treatments were randomized in each of three blocks (33 by 126.5 feet) on plots 5.75 by 33 feet in size. Nitrogen as ammonium nitrate was applied at 0, 40, 80, and 160 pounds to untreated land in each of the years 1952, 1953, 1954, and 1955. (All treatment rates are on a per-acre basis.) A separate treatment was 160 pounds of P_2O_5 as treble superphosphate in combination with 160 pounds of N. Another group of treatments consisted of annual applications of 20, 40, 80, and 160 pounds of N for the 4-year period and 160 pounds of P_2O_5 in combination with 160 pounds of N. Thus, treatments fertilized every year received a total of 80, 160, 320, and 640 pounds of N and 640 pounds of P_2O_5 plus 640 pounds of N during the course of the experiment. Applications were made in April of each year.

[1] In cooperation with the South Dakota Agricultural Experiment Station.

[2] Italic figures in parentheses refer to Literature Cited, p. 23.

Nitrogen was broadcast on the soil surface. Phosphorus was drilled into the soil to a depth varying from 1 to 2 inches. Forage yield measurements were made and plant samples were collected at time of harvest for moisture and chemical determinations. Harvest was usually completed by July 4.

Total phosphorus in the plant material was determined by the digestion method of Bolin and Stamberg (*4*) and the colorimetric method of Barton (*3*). Nitrogen content of the forage was determined by the Gunning method (*2*).

Two methods were used to determine the effect of various fertilizer treatments on moisture extraction by grass. Bouyoucos moisture blocks were installed in the 0-, 40-, 80-, and 160-pound nitrogen treatments in 1954 and 1955 at profile depths of 6, 12, 18, 24, 30, and 36 inches. Electrical resistance measurements were made periodically from May 18 through July 14. In 1956 the experimental area was irrigated to establish a uniform soil moisture condition and to wet the profile to a depth of 4 feet. Gravimetric soil samples were taken periodically from initiation of growth in April until harvest in June. Plots that had received a total of 640 pounds of N and 640 pounds of P_2O_5 plus 640 pounds of N were selected for study. Soil samples were obtained from depths of 0 to 6, 6 to 12, 12 to 18, 18 to 24, and 24 to 30 inches. These treatments were also sampled in 1957.

Seasonal precipitation and mean maximum temperature data were computed for the period March 30 through June 22. Evapotranspiration data were calculated for the period of growth initiation through harvest.

RESULTS AND DISCUSSION

The response to nitrogen by bromegrass and crested wheatgrass was marked by earlier—6 to 10 days—initiation of spring growth, by darker color, and by increased vegetative growth. Potential seed production, as indicated by the amount of heading, also improved with nitrogen fertilization. Head development was observed to be 10 percent for no fertilization and 31 percent for 160 pounds of nitrogen in a relatively dry year (1952). By contrast, the comparable observations in a wet year (1953) were 38 percent and 80 percent, respectively.

Forage Production

Data for yield and for percentage of nitrogen and percentage of phosphorus contained in grass are given in tables 11 through 13 in the Appendix. The fertilizer production functions (fig. 1), as described by the regression model log $Y=a+b$ log N where Y and N represent pounds per acre of forage produced and nitrogen applied, respectively, suggest that yield increased at a diminishing rate as fertilizer rate increased.

The nature of the response function was influenced by the availability of phosphorus (table 11). Comparison of the yields obtained with the 160-pound nitrogen addition with those from the combined 160-pound nitrogen and 160-pound phosphorus treatment shows that lack of phosphorus limited the response of grass to nitrogen. This was especially noticeable during years of favorable rainfall.

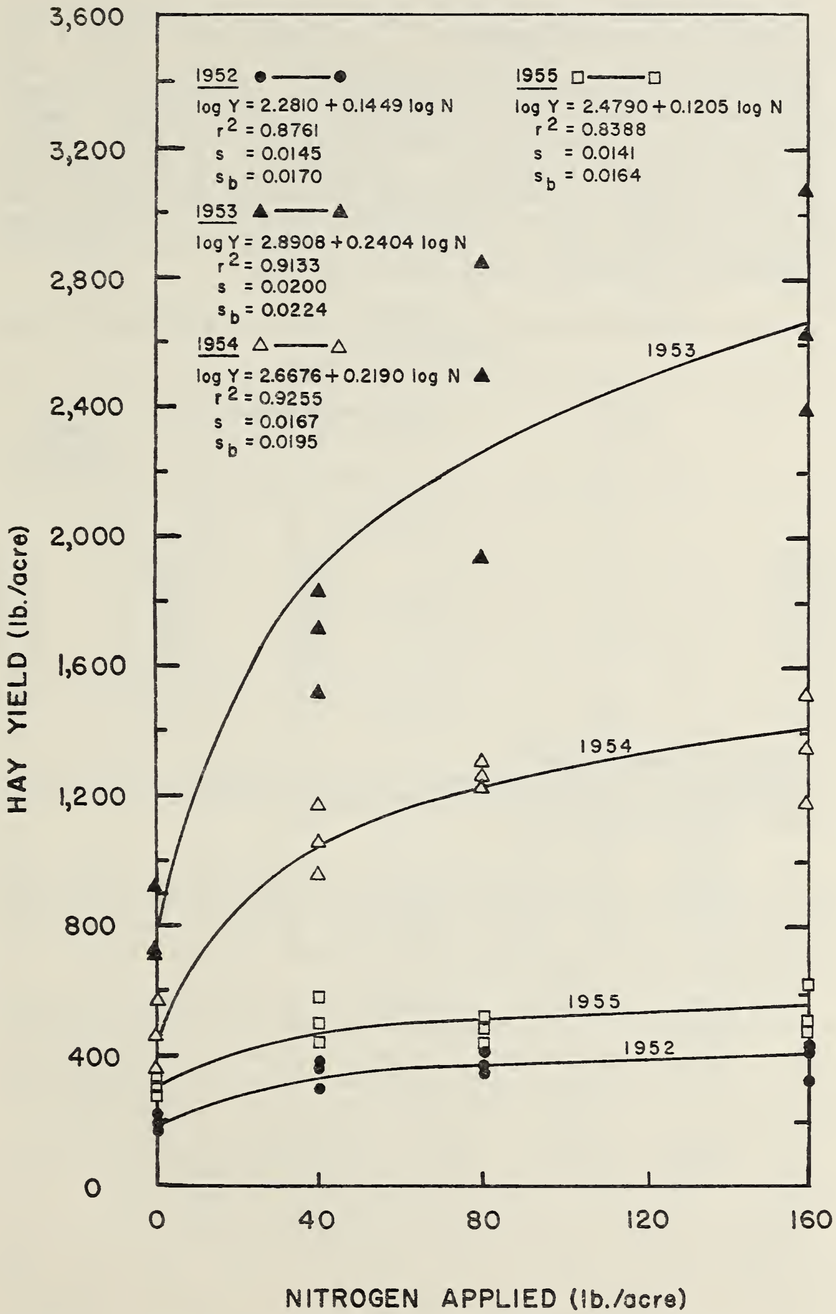

FIGURE 1.—Grass yield response from nitrogen fertilizer for different years.

Nitrogen significantly increased yields over the nonfertilized yields in each of the years of application. It is readily seen in figure 1 that the magnitude of the response varied between years. In 1952 and 1955, when rainfall was below normal (table 1), 40 pounds of nitrogen produced total yields that were 157 and 196 pounds greater, respectively, than the nonfertilized forage yields for those years. Under the more favorable precipitation conditions of 1953 and 1954, the 40-pound nitrogen additions produced total yields that were 900 and 584 pounds greater, respectively, than the yields of the nonfertilized forage for those years. A significant response to the immediate application of phosphorus was obtained in 1953.

TABLE 1.—*Climatic data for the Newell Field Station during the period 1952 to 1957* [1]

Year	Seasonal precipitation		Mean seasonal maximum temperature
	Actual	Effective [2]	
	Inches	*Inches*	*°F.*
1952	3.06	2.95	71.9
1953	9.85	8.19	61.3
1954	6.65	7.38	62.3
1955	3.88	4.08	68.6
1956	4.79	4.78	66.7
1957	7.30	7.93	61.6
Mean	5.92	5.89	65.4

[1] March 30 through June 22.
[2] Adjusted for maximum temperature by the regression equation: log S= 12.3299–6.3872 log T; where S is effective seasonal precipitation and T is the mean maximum temperature.

To establish a basis for comparison of the effects of single and annual fertilizer additions apart from the year effects, ratios of fertilized forage yields to nonfertilized forage yields within the same year are presented in table 2. Differences between the yield ratios were evaluated by the t-distribution test (*15*).

The annual application of nitrogen did not significantly increase hay yields over the single nitrogen application (t=1.582, P<10 percent). Annual applications of 20 and 40 pounds of nitrogen for 4 years produced total hay yields of 3,028 and 4,145 pounds, respectively, while a single equivalent application of 80 and 160 pounds of nitrogen in 1952 produced respective total yields of 3,393 and 4,810 pounds.

The annual phosphorus additions significantly increased forage yields over the single application of phosphorus (t=5.469, P<0.05 percent). Most of the increase occurred in 1954 and 1957.

Residual nitrogen significantly increased hay yields over the nonfertilized forage yields in each year except 1957 (table 3). The quantity of nitrogen initially applied and its immediate utilization determined the longevity of crop response to residual fertilizer. Grass fertilized with 160 pounds of nitrogen responded significantly to residual nitrogen for two cropping seasons, whereas the residual

TABLE 2.—*Comparison of single and annual applications of fertilizers on hay yields*

Fertilizer applied[1]		Yield ratio[2]									
		1953		1954		1955		1956		1957	
N	P_2O_5	Single	Annual	Single	Annual	Single	Annual	Single	Annual	Single	Annual
Lb./acre	*Lb./acre*										
40	0	2. 12	2. 76	2. 24	2. 46	1. 66	1. 55	1. 69	1. 80	1. 10	1. 00
80	0	3. 04	3. 45	2. 69	2. 76	1. 75	1. 89	2. 26	2. 00	1. 49	1. 46
160	0	3. 37	3. 38	2. 92	3. 31	1. 84	1. 80	3. 07	2. 80	1. 72	2. 16
160	160	4. 83	4. 89	3. 15	4. 54	1. 73	1. 67	3. 10	3. 13	1. 61	2. 23

t-distribution test:

$$t(\text{nitrogen}) = \frac{0.1092-0}{0.0689} = 1.582,\ n=15,\ P<10 \text{ percent.}$$

$$t(\text{phosphorus}) = \frac{0.4042-0}{0.0739} = 5.469,\ n=15,\ P<0.5 \text{ percent.}$$

[1] Applied in years 1952, 1953, 1954, and 1955.

[2] Yield ratio $= \dfrac{\text{Fertilized forage yields}}{\text{Nonfertilized forage yields}}$.

effects of the 80-pound nitrogen applications were apparent for one cropping season. A comparison of the residual responses from the nitrogen applications of 1952 and 1953 shows that when the immediate utilization of nitrogen was large (1953), plant response to residual fertilizer effects was small. Residual nitrogen from the application of 40, 80, and 160 pounds of nitrogen in the low rainfall year of 1952 produced respective yield increases over the nonfertilized forage yields of 53.4, 157.0, and 264.7 percent in 1953, compared to yield increases in 1954 of 23.1, 55.2, and 155.2 percent from nitrogen carried over from the 1953 applications of 40, 80, and 160 pounds of nitrogen, respectively.

TABLE 3.—*Effect of residual fertilizer on hay yields*

Year applied	Fertilizer applied		Change in yield [1]				
	N	P_2O_5	1953	1954	1955	1956	1957
	Lb./acre	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*
1952	40	0	429	98	36	2	−107
	80	0	1, 261	187	41	33	−122
	160	0	2, 126	658	96	280	20
	160	160	2, 242	528	75	289	−52
1953	40	0		49	15	−60	8
	80	0		260	38	−38	−78
	160	0		731	124	165	103
	160	160		723	147	369	29
1954	40	0			44	209	−31
	80	0			128	527	−53
	160	0			183	869	90
	160	160			162	1, 136	266
1955	40	0				542	100
	80	0				989	497
	160	0				1, 628	735
	160	160				1, 649	623
L.s.d. at 5-percent level			588	220	99	515	469
L.s.d. at 1-percent level			797	296	132	688	627

[1] Change in yield as compared to nonfertilized hay yields.

A significant yield response to residual phosphorus was obtained in 1954 with the annual 160-pound nitrogen and 160-pound phosphorus treatment. Residual phosphorus from the 320 pounds of P_2O_5 previously applied produced 577 pounds of hay in 1954. In another study, Thomas and Osenbrug (*17*) obtained significant yield increases from residual phosphorus on Pierre clay when the quantity of phosphorus applied exceeded 226 pounds of P_2O_5 per acre, which was 20 percent of the phosphorus absorption capacity (*11*).

The importance of seasonal precipitation on grass yield at different levels of fertilization was evaluated by means of regression techniques (*15*). Regression equations expressing yield (Y) as a function of the effective seasonal precipitation (S) are shown in table 4. Temperature may affect this relationship (*17*); therefore, seasonal precipitation data were corrected for the influence of the

TABLE 4.—*Dependence of grass forage yields (Y) on effective seasonal precipitation (S) at different levels of nitrogen fertilizer*

Fertilizer applied		Regressions ($Y=a+bS$)	Standard error (s_e)	Standard error of b (s_b)	Percent reduction in total sum of squares due to S	$F=\frac{RMS^{1}}{s_e^2}$
N	P_2O_5					
Lb./acre	*Lb./acre*					
0	0	$\log Y=2.0016+0.1019S$	0. 0245	0. 0121	87. 59	70. 40**
40	0	$\log Y=2.2267+0.1163S$	. 0212	. 0098	93. 25	139. 00**
80	0	$\log Y=2.0659+0.1520S$	. 0212	. 0094	96. 02	241. 91**
160	0	$\log Y=2.0937+0.1538S$	. 0245	. 0112	94. 99	189. 35**
160	160	$\log Y=2.0197+0.1758S$	. 0106	. 0152	92. 87	129. 99**

[1] RMS=Regression mean square.
**=Significant at 1-percent level.

mean maximum temperature (T) by the equation: $\log S = 12.3299 - 6.3872 \log T$. The regression of seasonal precipitation on mean maximum temperature was highly significant. The corrected precipitation values are shown in table 1 as "effective precipitation." As the variability in yield determinations at a given fertilization level increased with increasing yields, the yield data were transformed to a logarithmic scale.

The regression on effective seasonal precipitation was highly significant at each level of fertilization (table 4). The reductions in total sum of squares show that 88 to 96 percent of the yield variance was associated with the variability in seasonal precipitation. The regression coefficients increased with increasing levels of fertilization, which suggests that the efficiency of use of seasonal precipitation was improved by the application of nitrogen.

Graphical representations of the regression surfaces of table 4 are shown in figures 2 and 3. The nonlinear nature of the relationship between seasonal precipitation and yields is readily seen. Within the seasonal precipitation limits of 3 to 10 inches all applications of nitrogen fertilizer significantly increased yields (fig. 2) over the nonfertilized yields.

Figure 3 illustrates the effect of seasonal precipitation on the response of grass to application of phosphorus fertilizer. The differences in yield between the 160-pound nitrogen and the combination 160-pound nitrogen plus 160-pound phosphorus treatments were tested for significance. Yield differences greater than 319 pounds per acre were highly significant ($t=45.9$, $P<0.01$ percent). A significant response to phosphorus was obtained only in 1953, a year of relatively high seasonal precipitation. Power and coworkers (*12*) found that response to phosphorus fertilizer by spring wheat increased linearly with seasonal precipitation if the soil phosphorus was in an intermediate range. Available soil phosphorus in Pierre clay, as measured by the $NaHCO_3$ method, was within the medium range of 5 to 10 p.p.m. phosphorus.

Chemical Composition of Forage

The application of nitrogen significantly increased the nitrogen content of the grass over the nitrogen concentration of the nonfertilized grass (fig. 4). It is seen that the form of the regression models expressing the nitrogen content of grass as a function of nitrogen fertilizer varied between years. This severely limits the usefulness of the equations for predictive purposes. Single nitrogen additions were as effective as annual nitrogen applications in raising the nitrogen level of the grass. One application of 40, 80, and 160 pounds of nitrogen increased the nitrogen content of the grass from a mean of 1.52 percent for nonfertilized grass to 2.00, 2.27, and 2.58 percent, respectively. Yearly applications of 40, 80, and 160 pounds of nitrogen during the same period (1952 through 1955) produced grass with respective mean nitrogen percentages of 2.09, 2.28, and 2.57.

The resultant increase in percentage of nitrogen in forage with additions of nitrogen fertilizer was modified with increasing amount of seasonal precipitation. Forty pounds of nitrogen in a dry year

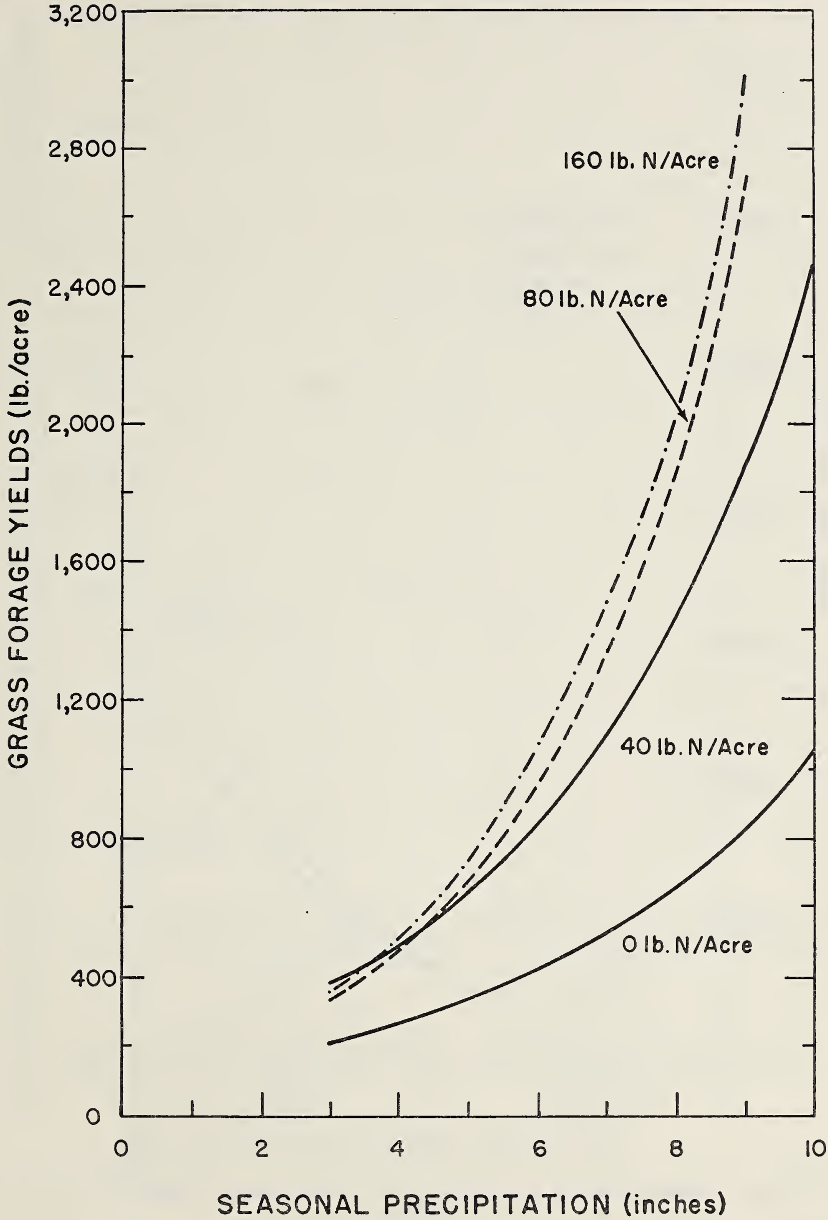

FIGURE 2.—Relation of seasonal precipitation to forage yields at different levels of nitrogen fertilizer.

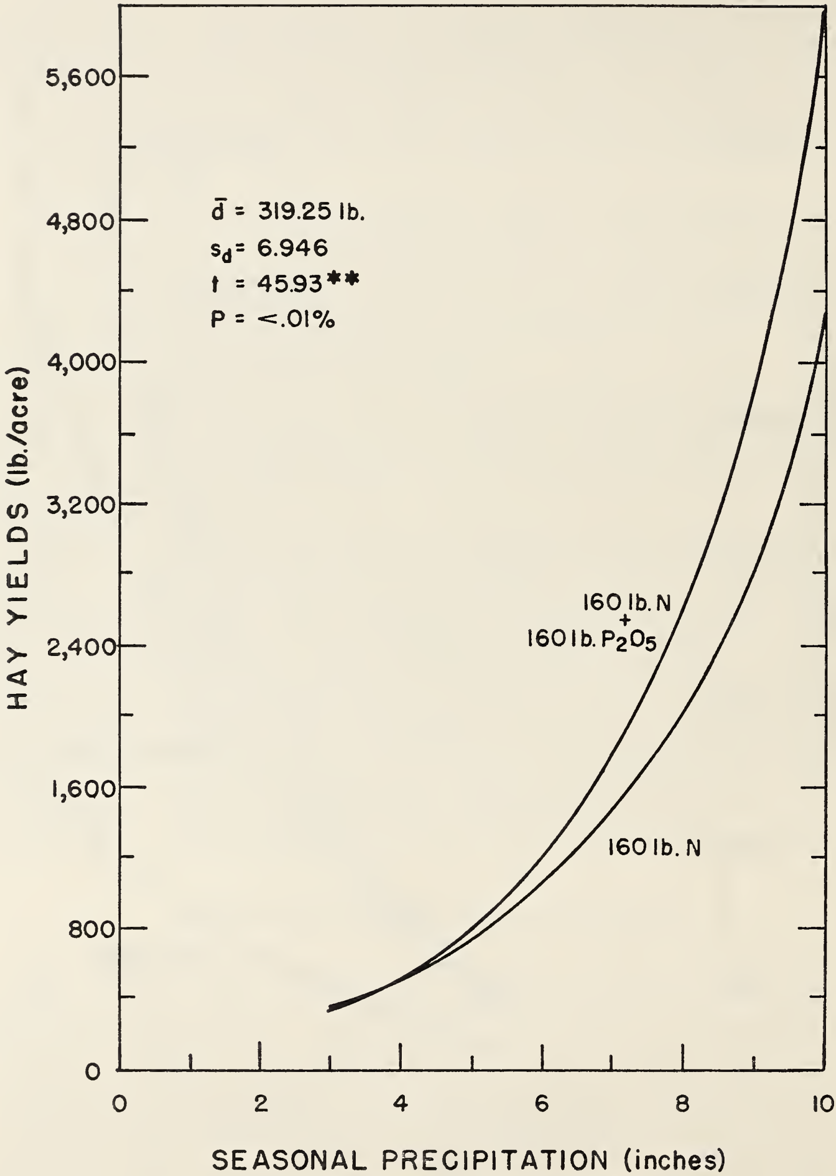

FIGURE 3.—Effect of seasonal precipitation and phosphorus fertilizer on forage yields.

(1952) increased the nitrogen percentage from 1.31 to 2.34 percent; whereas, in 1953, with a larger amount of rainfall, 40 pounds of nitrogen changed the nitrogen content of the grass from 1.58 to 1.70 percent. The lower percentage of nitrogen values obtained at a given nitrogen fertilizer rate with high seasonal rainfall was due to

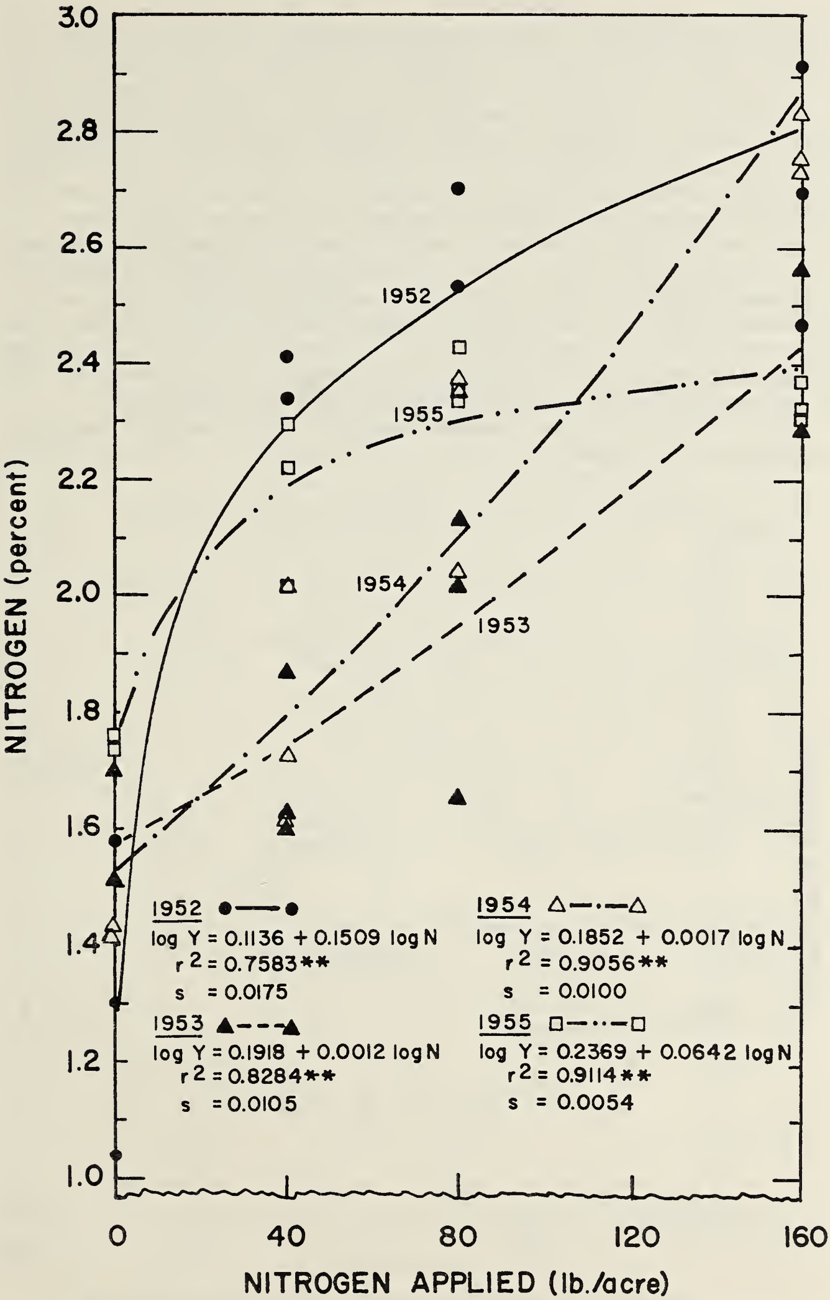

FIGURE 4.—Relation of nitrogen content of grass (Y) to the application of fertilizer nitrogen (N) for different years.

the enhanced crop growth. The low nitrogen values (table 12 Appendix) obtained in 1957 were due in part to the maturity of the grass. Harvest in 1957 was nearly 3 weeks later than in other years.

The effect of phosphorus fertilizer on the grass nitrogen content was erratic. In years of low rainfall, 1952 and 1955, the addition of phosphorus in conjunction with nitrogen significantly increased the nitrogen content of the grass over the effect of nitrogen alone. Under the more favorable moisture conditions of 1953 and 1954, however, phosphorus had no significant effect on the nitrogen percentage.

The regression of yield on the percentage of nitrogen in the grass was highly significant in those years in which nitrogen fertilizer was applied (table 5). The percentage reduction in the total sum of squares indicates that 52 to 92 percent of the yield variance was associated with the variability in the nitrogen content of the forage. The contribution of the nitrogen concentration in the forage to yield was least well defined during years of favorable precipitation.

The effect of first-year residual nitrogen on the nitrogen content of the grass is illustrated in figure 5. The notations, "R-1952, R-1953,

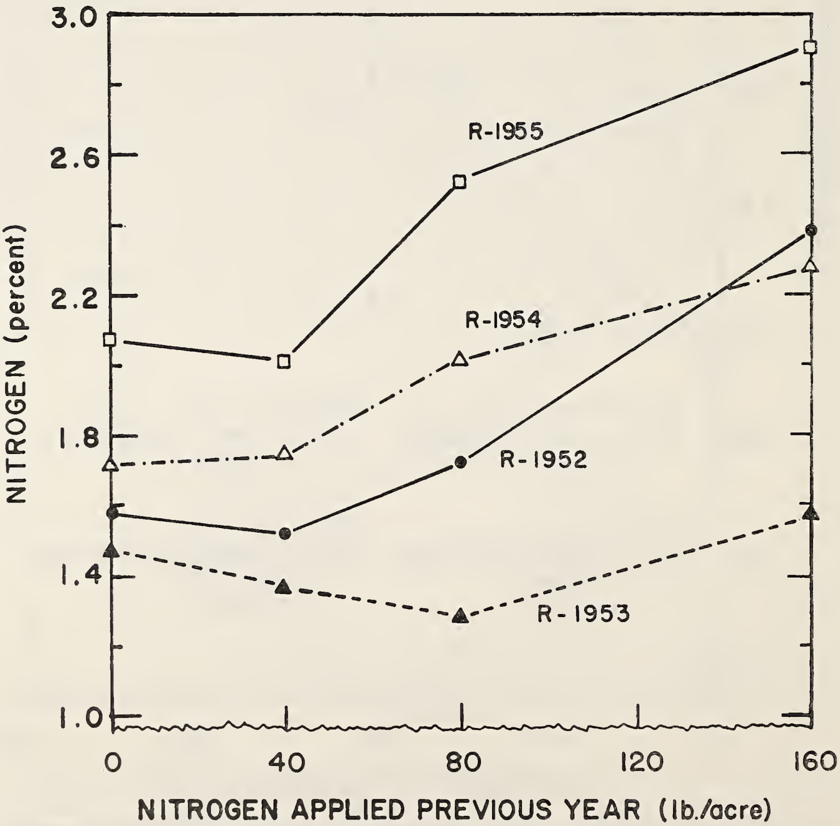

FIGURE 5.—Effect of first-year residual nitrogen on nitrogen content of grass.

etc." indicate the year in which the fertilizer was applied. The persistence of the residual nitrogen fertilizer was related to the initial rate of application. Residual nitrogen from the 40-pound application had no effect on the nitrogen percentage even though hay yields were significantly increased. Nitrogen carryover from the 80 pounds of nitrogen applied in 1954 or 1955 produced a significant increase in percentage of nitrogen in the forage for one additional growing season. However, 80 pounds of nitrogen applied in 1952 or 1953 did not produce a significant residual response. The residual effects of the 160-pound nitrogen additions on the nitrogen content of grass were evident for 1 to 2 cropping seasons.

Annual applications of fertilizer nitrogen obviated the response to residual nitrogen. Failure to attain a significant increase in percentage of nitrogen in forage from the accumulated nitrogen additions to the soil over that attained with a single nitrogen application in 1953, 1954, and 1955 may be regarded as evidence in support of the postulated suppressive action.

The phosphorus content of the grass was associated with the quantity of nitrogen fertilizer applied. The regression on nitrogen fertilizer was significant in every year except 1954 (table 6). Evidently in this year the logarithmic transformation did not adequately stabilize the variability of the phosphorus concentration. The reduction in percentage of phosphorus in the grass with increasing levels of nitrogen fertilizer was due mainly to an increase in crop growth. The phosphorus content of the grass increased with an increase in seasonal precipitation. The availability to the grass of soil phosphorus was evidently influenced by soil moisture conditions. Such a relationship has been reported by Power and coworkers (*12*).

A depressant action of residual nitrogen on percentage of phosphorus in forage was noted for several years (fig. 6). Additions of 80 and 160 pounds of nitrogen in 1952 significantly decreased the phosphorus percentage for five cropping seasons. The addition of phosphorus fertilizer in combination with nitrogen partly counteracted the effect of nitrogen alone.

Forage yields from both fertilizer nitrogen and residual nitrogen treatments for all years may be considered to be a function of the percentages of nitrogen and phosphorus in the forage. The percentage reduction in total sum of squares due to regression on both nitrogen and phosphorus shows that 69 to 99 percent of the yield variance was associated with the variability in the nitrogen and phosphorus content of the grass (table 7). The magnitude of this reduction in regression decreased with time from fertilizer application.

Comparison of the independent and combined effects of nitrogen and phosphorus on yields in reducing the total sum of squares suggests that the percentage of phosphorus in the forage was correlated with the nitrogen content. Estimates of these correlations are shown in table 8. The negative association is well defined and results from the increase in plant growth after nitrogen fertilization. Other workers have found a positive correlation between the nitrogen and phosphorus content of grasses (*6*, *7*, *13*).

TABLE 5.—*Regression equations relating grass yields (Y) to the nitrogen content of the grass (N)*

Year	Regressions ($Y=a+b\ N$)	Standard error (s_e)	Standard error of b (s_b)	Percent reduction in total sum of squares due to N	$F=\frac{RMS}{s_e^2}$ [1]
1952	$Y=36.19+127.31\ N$	12. 2066	23. 5337	69. 23	29. 26**
1953	$\log Y=2.9049+1.3316 \log N$	. 0207	. 2286	60. 59	33. 90**
1954	$\log Y=2.6316+1.3197 \log N$	. 0243	. 2683	52. 35	24. 19**
1955	$Y=-83.85+252.94\ N$	3. 8832	15. 8861	92. 01	253. 50**

[1] *RMS*=Regression mean square.
**=Significant at 1-percent level.

TABLE 6.—*Regression equations relating the phosphorus content of grass (Y) to the application of nitrogen fertilizer (N) for different years*

Year	Regressions ($Y=a+b\ N$)	Standard error (s_e)	Standard error of b (s_b)	Percent reduction in total sum of squares	$F=\frac{RMS}{s_e^2}$ [1]
1952	$\log Y=-1.3664+0.0008\ N$	0. 0144	0. 0002	57. 09	13. 31**
1953	$\log Y=-1.4292+0.0006\ N$	. 0143	. 0002	38. 75	6. 32*
1954	$\log Y=-1.4097+0.0004\ N$	. 0120	. 0002	25. 86	3. 49
1955	$\log Y=-1.1826+0.0005\ N$	. 0088	. 0001	52. 76	11. 17**

[1] *RMS*=Regression mean square.
* =Significant at 5-percent level; **=significant at 1-percent level.

TABLE 7.—*Multiple regression equations relating grass yields (Y) to the nitrogen (N) and phosphorus (P) concentration in the forage at harvest*

Year	Regressions	Standard errors			Standard partial regression coefficients		Reduction in regression (percentage of total *SS*) due to—			
		s_e	$s(b_n)$	$s(b_p)$	$b'_{YN \cdot P}$	$b'_{YP \cdot N}$	*N* alone	*P* after *N*	*P* alone	*N* after *P*
1952	$Y=41.5+135.0N-109.6P$	4. 6	21. 9	115. 3	0. 950	−0. 043	99. 82	−0. 67	83. 61	15. 53
1953	$Y=4380.3+868.8N-16691.0P$	37. 4	114. 6	1906. 7	. 518	−. 598	73. 25	24. 27	79. 13	18. 39
1954	$Y=2307.6+421.1N-8839.4P$	26. 1	63. 4	1251. 7	. 560	−. 596	63. 58	29. 88	67. 00	26. 45
1955	$Y=247.9+213.1N-1784.9P$	7. 3	26. 3	631. 2	. 781	−. 273	83. 59	6. 19	45. 24	44. 55
1956	$Y=1732.3+572.2N-7136.6P$	68. 2	387. 1	4322. 0	. 408	−. 456	64. 12	5. 34	65. 08	4. 38
1957	$Y=1294.9+1064.9N-7389.6P$	42. 9	40. 7	1347. 2	. 441	−. 531	62. 30	16. 03	67. 30	11. 02

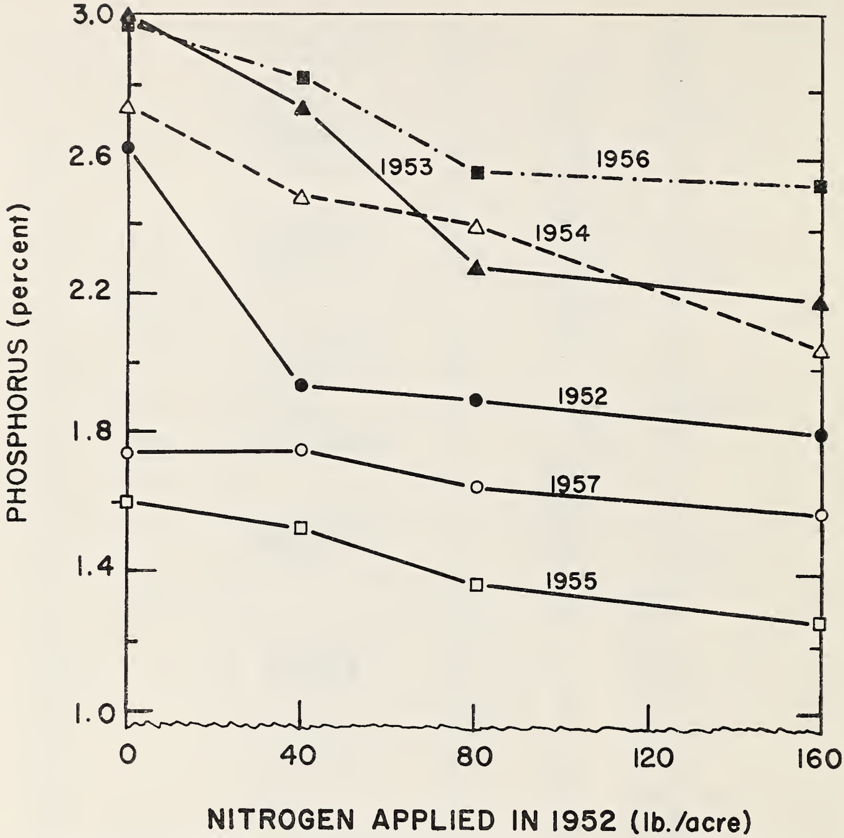

FIGURE 6.—Effect of residual nitrogen from 1952 fertilizer application on phosphorus content of grass.

There is some evidence to suggest that nitrogen was more effective than phosphorus in determining yields. Comparison of the standard partial regression coefficients, without regard to sign, indicate that nitrogen content of the grass was 22.1 to 2.9 times more effective than percentage of phosphorus in determining yields under conditions of low seasonal rainfall in 1952 and 1955 (table 7). Phosphorus content of the grass during years of relatively high seasonal precipitation was nearly as effective as percentage of nitrogen in determining yields. The negative standard partial regression coefficients ($b'_{YP \cdot N}$) also suggest that yields were limited by an inadequate phosphorus supply. This was further evidenced by the large yield response to phosphorus fertilizer in 1953 and 1954 (table 11, Appendix). The reductions in total sum of squares due to the independent effect of both nitrogen and phosphorus were significant in each year except 1956.

Nitrogen Recovered

The relationship between percentage of nitrogen recovered and quantity of nitrogen applied over several growing seasons is shown

TABLE 8.—*Correlation between percentage of nitrogen and phosphorus in grass*

Year	Correlation estimate [1]	Approximate 95 percent confidence limits on correlation coefficients
1952	−0.909*	$-0.994<\rho<-0.091$
1953	−.577*	$-.883<\rho<-.008$
1954	−.403	$-.767<\rho<.160$
1955	−.523**	$-.784<\rho<-.105$
1956	−.846**	$-.937<\rho<-.646$
1957	−.656**	$-.851<\rho<-.301$

[1] *=Significant at 5-percent level; **=significant at 1-percent level.

in figure 7. The percentage of nitrogen recovered was calculated from the relation:

$$\frac{\text{total yield of } N - \text{total yield of } N \text{ in check}}{\text{total } N \text{ applied (fertilizer)}}$$

and was based on cumulative total nitrogen values for the years under consideration. The family of curves for the 1952 nitrogen addition show the effect of initial level of nitrogen fertilizer on percentage of recovery when nitrogen utilization in the year of application was low. The largest percentage of recovery was obtained in the first residual year of 1953. The percentage recovery of nitrogen increased with the level of application. In two cropping seasons the respective recovery of the 40- and 160-pound nitrogen additions were 31.1 and 40.4 percent. Continued cropping increased the percentage of recovery slightly. After five cropping seasons a total of 35.1 and 51.2 percent, respectively, of the 40 and 160 pounds of applied nitrogen were recovered. The nitrogen content of the nonfertilized grass was slightly higher than that of grass previously fertilized in the sixth cropping season. This resulted in a slight decrease in the percentage of nitrogen recovered.

The total percentage of recovery of nitrogen applied in 1953 was slightly higher than for the 1952 nitrogen additions. This was due mainly to the greater utilization of the direct nitrogen application in 1953. Recovery of the 40- and 80-pound nitrogen application was not appreciably increased by continued cropping.

The quantity of fertilizer nitrogen recovered in the grass was also influenced by the application of phosphorus (table 9). Comparison of the 160-pound nitrogen with the 160-pound nitrogen plus 160-pound phosphorus applications of 1953 show that phosphorus increased nitrogen uptake from 45.9 to 63.4 percent. This relationship was also noted in the other years of fertilizer applications.

Loss of fertilizer nitrogen by leaching, by solution in the runoff water after a rain, or by volatilization of N_2, NO, and NH_3 (*1*, *10*, *18*) could account for the poor recovery of nitrogen. Although rainfall

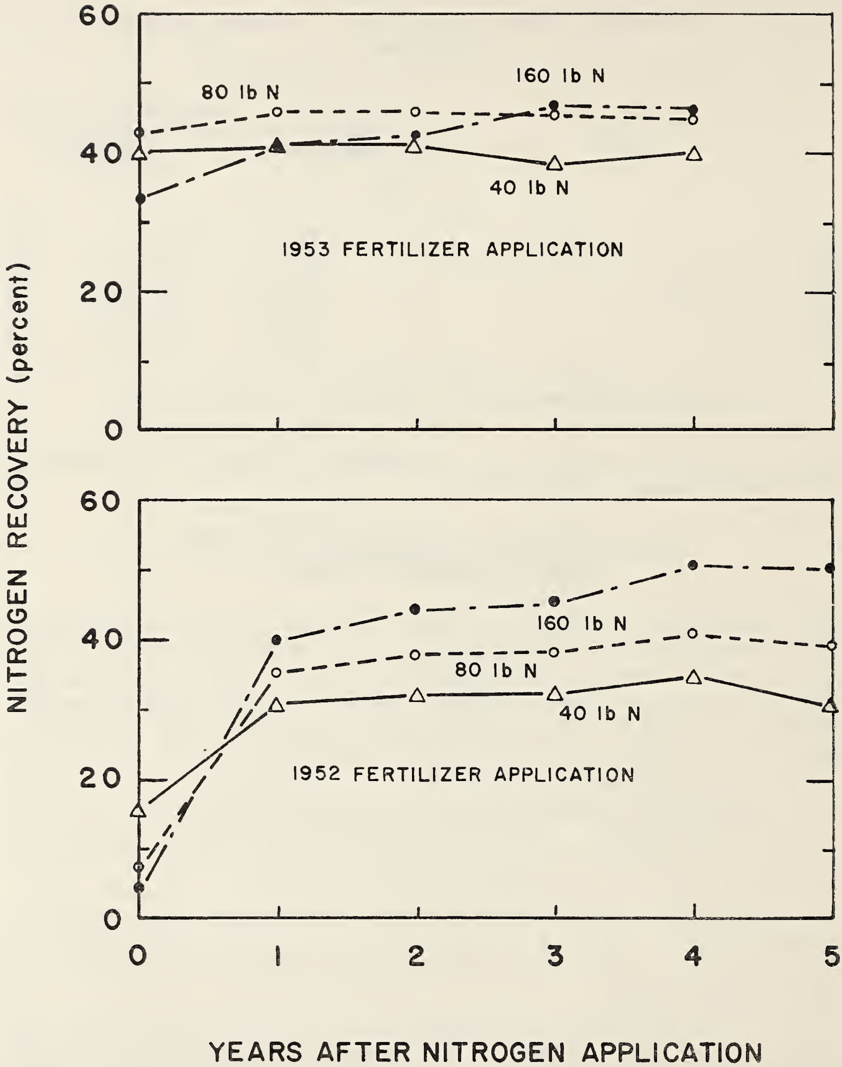

FIGURE 7.—Relationship of percentage of nitrogen recovery to initial nitrogen application level as a function of years of cropping.

generally occurred as high-intensity storms of short duration, loss of nitrogen in runoff water was of minor importance. Cracks that form in the Pierre clay as the soil becomes dry extend to depths of 24 inches and easily contained the runoff water. The nitrogen fertilizer could be carried into the subsoil under these conditions but would still be available to the grass. Electrical resistance measurements of soil moisture depletion indicated that grass roots were active at depths of 30 to 36 inches.

TABLE 9.—*Effect of phosphorus fertilizer on percentage of nitrogen recovered by grass*

Fertilizer applied		Year applied	Years of cropping	Nitrogen recovery
N	P_2O_5			
Lb./acre	*Lb./acre*			*Percent*
160	0	1952	6	50.8
160	160	1952	6	51.4
160	0	1953	5	45.9
160	160	1953	5	63.4
160	0	1954	4	41.9
160	160	1954	4	48.3
160	0	1955	3	43.9
160	160	1955	3	42.6
160(640)	0	1952–55[1]	6	26.1
160(640)	160(640)	1952–55[1]	6	36.8

[1] Fertilizer applied each year.

Soil Fertility–Moisture Relationships

Soil moisture exhaustion patterns in 1954 indicated that the water supply in the surface 6 inches of soil was depleted more rapidly if the fertility level was high (fig. 8). Soil moisture tension was measured from May 18 through July 14. At lower depths (2 to 3 feet) in the profile, moisture exhaustion was not affected by nitrogen fertilization. Kmock and others (*9*) found that winter wheat fertilized with nitrogen utilized moisture to a depth of 8 feet.

The Bouyoucos blocks used in 1954 to measure moisture depletion were not satisfactory in 1955, a dry season, as cracks occurred along the electrical leads and blocks. In April 1956, the soil was irrigated to fill the profile to a depth of 4 feet. Gravimetric soil samples were taken periodically and soil moisture determined. Moisture exhaustion patterns (figs. 9 and 10), similar to those of 1954, were found. As the main root system was established prior to the initiation of this study, the major zones of water exhaustion did not move down through the soil profile as the growing season progressed, a pattern previously reported for cultivated crops (*14*). Instead, moisture was withdrawn to some extent from throughout the profile.

Efficiency of moisture use by the grass was greatly improved by the use of fertilizers (table 10). In 1956, 1 inch of moisture on the nonfertilized grass produced 104 pounds of hay, whereas the nitrogen and nitrogen-phosphorus fertilized grass, respectively, produced 253 and 306 pounds of hay per inch of moisture. Similar results were obtained in 1957.

Soil fertility had a slight effect on evapotranspiration. The amount of water utilized was increased by fertilization in 1956. Soil fertility had very little effect on evapotranspiration in 1957 as moisture available for growth was never completely exhausted.

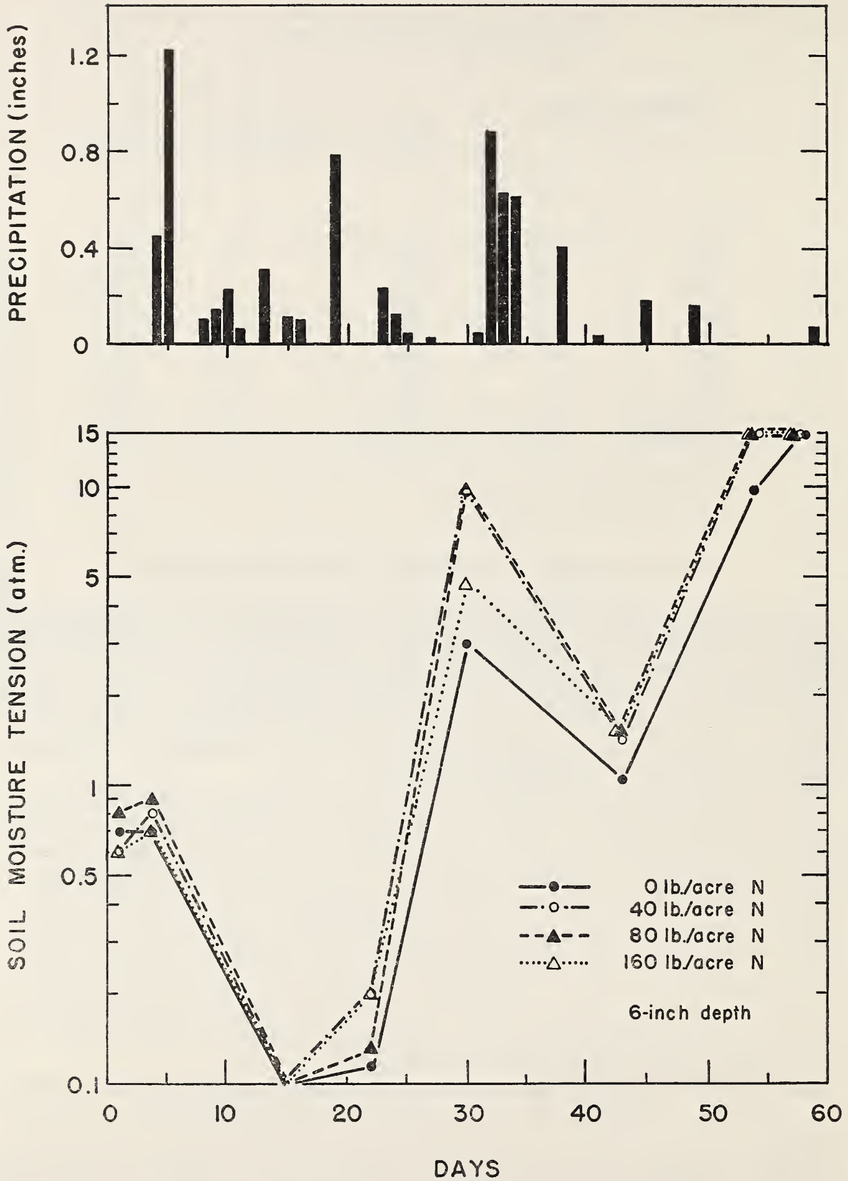

FIGURE 8.—Extraction of soil moisture by grass as influenced by nitrogen fertilization, May 18 through July 14, 1954.

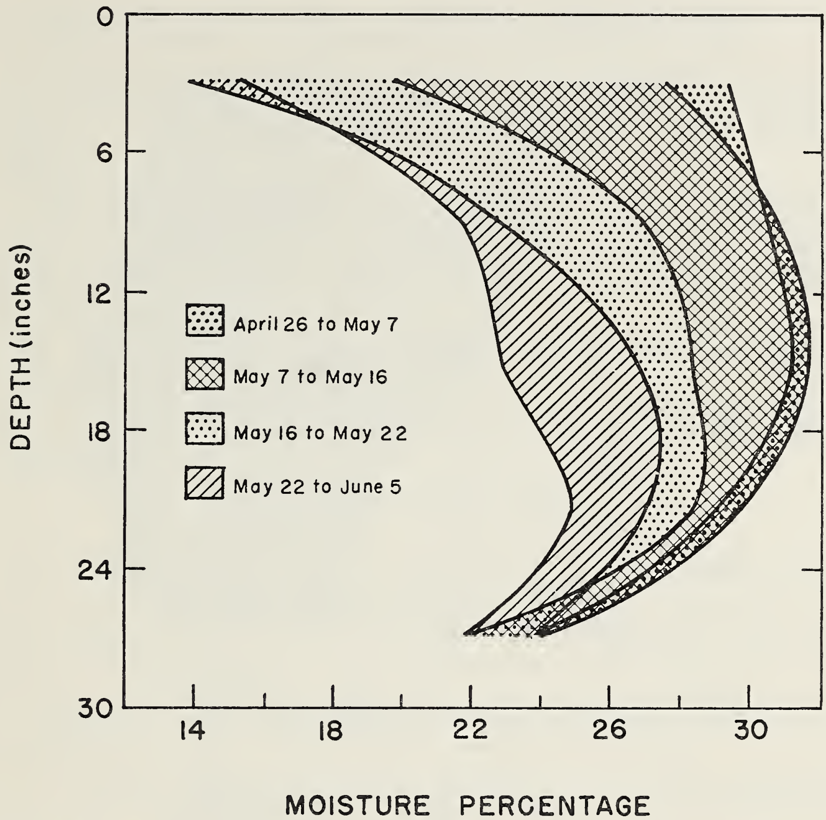

FIGURE 9.—Soil moisture profile of nonfertilized grass, showing zones of water disappearance during the growing season, 1956.

TABLE 10.—*Effect of residual fertilizer on evapotranspiration and moisture use by grass*

Year	Fertilizer applied		Hay yield	Evapotranspiration	Water use efficiency
	N	P_2O_5			
	Lb./acre	*Lb./acre*	*Lb./acre*	*Inches*	*Lb./inch*
	0	0	723	6. 97	103. 7
1956	640	0	2, 198	8. 68	253. 3
	640	640	2, 455	8. 01	306. 4
	0	0	1, 022	9. 54	107. 1
1957	640	0	2, 210	10. 52	210. 1
	640	640	2, 277	9. 84	231. 4

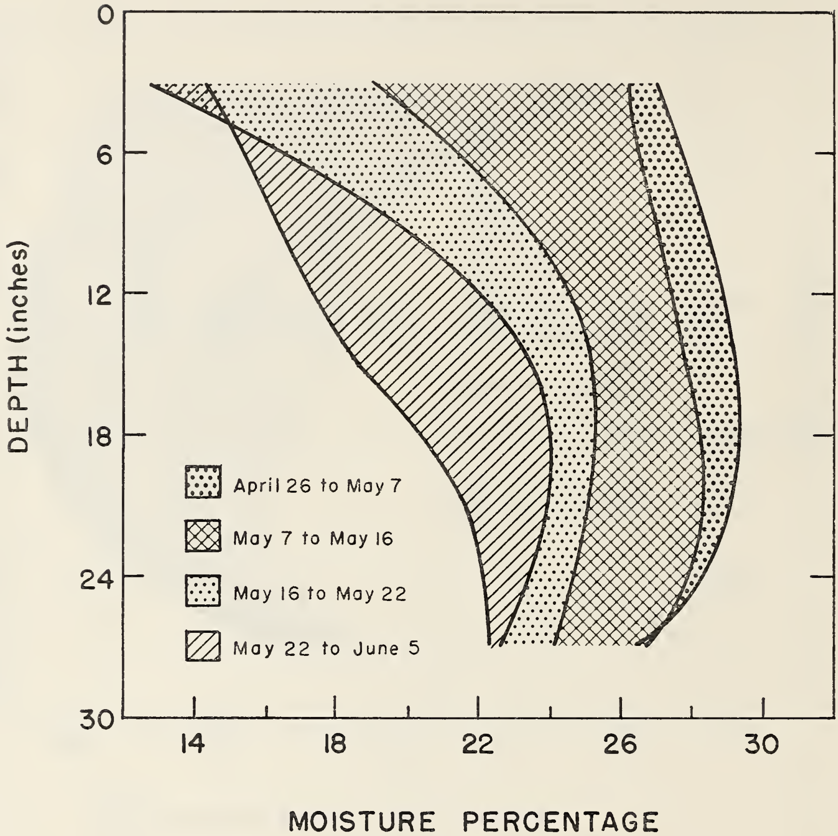

FIGURE 10.—Soil moisture profile of grass fertilized with nitrogen (640 lb. per acre), showing zones of water disappearance during the growing season, 1956.

SUMMARY

The effects of nitrogen, phosphorus, and seasonal precipitation on the yield and forage composition of crested wheatgrass-bromegrass were evaluated.

Hay yields were significantly increased by nitrogen fertilizer. The highest rates of nitrogen gave the greatest residual response in the 4 years after application.

The effect of seasonal precipitation on hay production was affected by the fertility level. Significant grass response to phosphorus fertilizer was obtained with high seasonal precipitation and when the quantity of phosphorus applied exceeded the soil phosphorus absorption capacity.

Nitrogen content of the grass increased with the application of nitrogen fertilizer and diminished with increasing amounts of seasonal precipitation. The addition of phosphorus fertilizer increased the nitrogen percentage only in years of low rainfall.

Nitrogen carryover from the 160-pound applications significantly increased the grass nitrogen content for two cropping seasons.

Forage yields were significantly related to the percentage of nitrogen and phosphorus in the grass. In years of low rainfall nitrogen was from 2.9 to 22.1 times more effective than phosphorus in determining yields. High hay yields were associated with grass having a high nitrogen content.

Recovery of the applied nitrogen fertilizer in the grass was affected by rate of application, seasonal precipitation, and adequacy of other nutrients. Maximum recovery of 63.4 percent was obtained with the 1953 application of 160 pounds of nitrogen in combination with 160 pounds of phosphorus.

High soil fertility favored a more rapid depletion of moisture from the surface 6 inches, but high fertility had no effect on moisture exhaustion from lower depths in the profile.

One inch of evapotranspiration produced 104 and 253 pounds of hay in 1956 on the 0- and 640-pound residual nitrogen treatments, respectively.

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APPENDIX

TABLE 11.—*Yields of hay as influenced by direct and residual nitrogen and phosphorus fertilizers*

Year applied	Fertilizer applied		Hay yields					
	N	P_2O_5	1952	1953	1954	1955	1956	1957
	Lb./acre	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*	*Lb./acre*
1952	0	0	188	803	471	296	723	1, 022
	40	0	379	1, 232	569	332	787	915
	80	0	334	2, 064	658	337	818	900
	160	0	360	2, 929	1, 129	392	1, 065	1, 042
	160	160	381	3, 045	999	371	1, 074	970
1953	40	0	----------	1, 703	520	311	725	1, 030
	80	0	----------	2, 439	731	334	747	944
	160	0	----------	2, 704	1, 202	420	949	1, 125
	160	160	----------	3, 879	1, 194	443	1, 154	1, 051
1954	40	0	----------	----------	1, 055	340	994	991
	80	0	----------	----------	1, 267	424	1, 312	969
	160	0	----------	----------	1, 375	479	1, 654	1, 112
	160	160	----------	----------	1, 486	458	1, 921	1, 288
1955	40	0	----------	----------	----------	492	1, 327	1, 122
	80	0	----------	----------	----------	519	1, 774	1, 519
	160	0	----------	----------	----------	543	2, 413	1, 757
	160	160	----------	----------	----------	513	2, 434	1, 645
1952–55 [1]	[2] 20 (80)	0	294	1, 481	853	400	904	1, 041
	[2] 40 (160)	0	310	2, 214	1, 161	460	1, 414	1, 018
	[2] 80 (320)	0	407	2, 773	1, 299	560	1, 571	1, 495
	[2] 160 (640)	0	403	2, 711	1, 559	533	2, 198	2, 210
	[2] 160 (640)	[2] 160 (640)	396	3, 924	2, 136	495	2, 455	2, 277
L.s.d. at 5-percent level			50	588	220	99	515	469
L.s.d. at 1-percent level			66	797	296	132	688	627

[1] Fertilizer applied each year on same plot.
[2] Figures in parentheses indicate total amount of fertilizer applied for 4-year period.

Table 12.—*Influence of direct and residual nitrogen and phosphorus fertilizers on nitrogen content of grass*

Year applied	Fertilizer applied		Nitrogen					
	N	P_2O_5	1952	1953	1954	1955	1956	1957
	Lb./acre	*Lb./acre*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1952	0	0	1.31	1.58	1.49	1.73	2.08	0.99
	40	0	2.34	1.52	1.31	1.62	2.19	.95
	80	0	2.53	1.71	1.39	1.63	2.20	.96
	160	0	2.78	2.38	1.34	1.73	2.24	.92
	160	160	2.96	2.34	1.31	1.68	2.34	.93
1953	40	0	----------	1.70	1.38	1.65	2.11	1.05
	80	0	----------	1.94	1.30	1.57	2.12	.95
	160	0	----------	2.46	1.57	1.81	2.28	.89
	160	160	----------	2.40	1.50	1.55	2.15	.95
1954	40	0	----------	----------	1.79	1.74	2.10	.94
	80	0	----------	----------	2.26	2.03	2.25	.95
	160	0	----------	----------	2.77	2.27	2.79	.95
	160	160	----------	----------	2.66	2.35	2.85	.84
1955	40	0	----------	----------	----------	2.18	2.02	.94
	80	0	----------	----------	----------	2.37	2.53	.93
	160	0	----------	----------	----------	2.34	2.92	1.01
	160	160	----------	----------	----------	2.54	2.83	1.02
1952–55 [1]	[2] 20 (80)	0	2.03	1.49	1.58	2.00	2.18	.95
	[2] 40 (160)	0	2.40	1.79	1.90	2.29	2.23	.94
	[2] 80 (320)	0	2.64	2.24	2.06	2.21	3.04	1.05
	[2] 160 (640)	0	2.59	2.70	2.43	2.59	2.94	1.54
	[2] 160 (640)	[2] 160 (640)	2.90	2.58	2.91	2.32	2.86	1.44
L.s.d. at 5-percent level			0.29	0.22	0.22	0.16	0.29	0.12
L.s.d. at 1-percent level			.40	.30	.29	.20	.39	.16

[1] Fertilizer applied each year on same plot.
[2] Figures in parentheses indicate total amount of fertilizer applied for the 4-year period.

TABLE 13.—*Influence of direct and residual nitrogen and phosphorus fertilizers on the phosphorus content of grass*

Year applied	Fertilizer applied: N	Fertilizer applied: P_2O_5	Phosphorus: 1952	Phosphorus: 1953	Phosphorus: 1954	Phosphorus: 1955	Phosphorus: 1956	Phosphorus: 1957
	Lb./acre	*Lb./acre*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
	0	0	0.262	0.300	0.274	0.160	0.297	0.174
1952	40	0	.192	.273	.248	.153	.281	.175
	80	0	.197	.228	.240	.137	.255	.165
	160	0	.177	.219	.204	.126	.252	.157
	160	160	.188	.234	.223	.140	.276	.160
1953	40	0	----------	.232	.253	.157	.292	.175
	80	0	----------	.229	.252	.150	.295	.182
	160	0	----------	.227	.201	.129	.241	.161
	160	160	----------	.272	.266	.149	.308	.207
1954	40	0	----------	----------	.238	.170	.308	.192
	80	0	----------	----------	.228	.129	.273	.171
	160	0	----------	----------	.232	.132	.236	.126
	160	160	----------	----------	.287	.151	.244	.141
1955	40	0	----------	----------	----------	.134	.269	.167
	80	0	----------	----------	----------	.143	.245	.161
	160	0	----------	----------	----------	.127	.204	.127
	160	160	----------	----------	----------	.148	.233	.132
1952–55 [1]	[2] 20 (80)	0	.188	.245	.260	.132	.273	.168
	[2] 40 (160)	0	.196	.230	.229	.134	.246	.161
	[2] 80 (320)	0	.183	.216	.204	.128	.225	.115
	[2] 160 (640)	0	.183	.231	.200	.134	.213	.098
	[2] 160 (640)	[2] 160 (640)	.204	.273	.298	.161	.259	.132
L.s.d. at 5-percent level			0.016	0.027	0.034	0.020	0.037	0.028
L.s.d. at 1-percent level			.021	.037	.046	.027	.050	.038

[1] Fertilizer applied each year on same plot.
[2] Figures in parentheses indicate total amount of fertilizer applied for the 4-year period.

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